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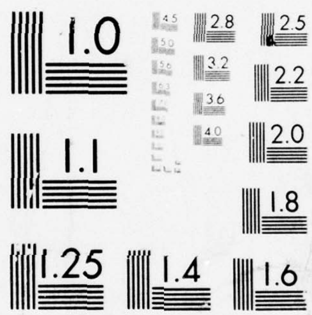

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SIMULATION OF ORIGINAL AND NAFEC-PROPOSED INTERMITTENT POSITIVE CONTROL COCKPIT DISPLAYS

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DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

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FINAL REPORT

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16. Abstract

In order to evaluate the adequacy of aircraft proximity warning and collision avoidance information pilot display, 14 alternative cockpit displays were compared to the original Intermittent Positive Control (IPC) BADCOM display in a subjective evaluation by 17 persons. A single display best incorporating the preferred features was then compared to the BADCOM display in a series of midair collisions simulated in the GAT-2 flight simulator. Twenty-four pilots participated in four test sessions, each with 15 simulated conflicts in each session. Both displays were employed to give IPC maneuver commands and, alternatively, to give proximity warnings without specific maneuver orders. The results from this study indicated that there was no overall significant difference between the two displays evaluated, based on measured pilot performance. However, it was found that the two-altitude sector presentation (NAFEC display) was significantly better than the three altitude sector presentation (BADCOM display) in terms of pilot performance. In addition to the objective evaluation results, the pilots indicated that (a) they preferred the NAFEC display, because of the POSITIVE command approach; and (b) they found the RESUME NAVIGATION command to be important, because it indicated when the threat had passed.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this report was to summarize the results of combined National Aviation Facilities Experimental Center (NAFEC) and Transportation Systems Center (TSC) efforts to define the nature of the cockpit display configuration that would adequately present (to the pilot) the proposed proximity warning and collision avoidance information that is expected to be generated by the ground-based computerized Intermittent Positive Control (IPC) System.

BACKGROUND.

IPC is a totally automated ground-based collision avoidance system which provides pilots with information on the location of nearby aircraft and collision avoidance instructions on an "as needed" basis. IPC operates in controlled, mixed, and uncontrolled airspace and provides protection to both controlled and uncontrolled aircraft. The IPC system provides the backup to the ATC system by issuing potential collision alerts to air traffic controllers and by issuing collision avoidance commands to controlled flights in cases in which controller action has failed to prevent an impending conflict.

In order for the ground system to provide complete IPC service, each aircraft in the airspace must be equipped with a transponder which provides the ground system with three-dimensional position information and a data link which permits the ground system to electronically send messages to the aircraft. Utilization of the Discrete Address Beacon System (DABS) transponder, currently under development by the Federal Aviation Administration (FAA), integrates both the surveillance and data link functions into a single unit. In addition, each aircraft must have an IPC display which presents to pilots collision avoidance commands derived by the ground-based system.

The IPC display is central to the entire IPC design, since it establishes the types of messages that the ground system can send to the pilot. Figure 1 presents the BADCOM IPC display which was proposed in the original system design concept.

This report summarizes two phases of IPC investigation. Phase I evaluates multiple alternatives to the initially proposed BADCOM display on a display-component basis to determine which component features might comprise an optimum display. Phase II utilizes a fabricated display incorporating the optimum display features determined from phase I in simulated IPC flight testing, along with the BADCOM display for operational comparison.

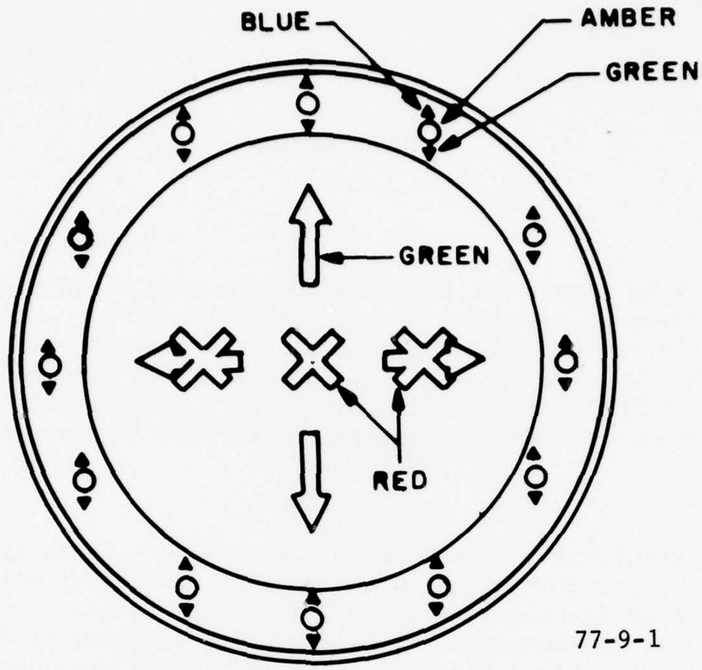


FIGURE 1. THE BADCOM IPC DISPLAY

PHASE I. IPC DISPLAY ALTERNATIVES EVALUATION

The display proposed in the original system design concept was the BADCOM display (figure 1). Since IPC development was approaching the point of simulation and flight test, NAFEC and TSC were asked to propose alternatives to the original display and provide data to the Systems Research and Development Service IPC program office on the utility of these alternate displays.

DESCRIPTION OF EQUIPMENT.

The BADCOM IPC display (figure 1) includes an outer ring of lights arranged in 12 groups of 3 lights stacked vertically, each group located at 1 of the 12 clock positions (i.e., spaced by 30°). They are referred to as proximity warning indicator (PWI) lights (or PWI ring) and permit the ground system to tell a pilot of the location of another aircraft relative to his own. By lighting any one of these proximity warning lights, the ground system is able to tell the pilot the relative bearing (i.e., 1 o'clock, 2 o'clock, etc.) and the relative altitude (i.e., up, down, coaltitude) of any other nearby aircraft. A top light is lit to indicate an aircraft above (e.g., 500 to 2,000 feet above), a middle light for coaltitude (500 feet below to 500 feet above), or a bottom light for below (500 to 2,000 feet below).

These proximity warning lights can be flashed or steadily lit. A flashing light indicates traffic which represents a potential collision threat; a steady light indicates traffic which is not currently on a collision course. In addition, the display includes a set of "do" arrows and "don't" crosses which, when lit by the ground system, tell the pilot to "do" a particular maneuver or "don't" do a particular maneuver. A "do" command is displayed by lighting an arrow and two crosses. A "don't" command is displayed by lighting a single cross. Any time a "do" or "don't" command is displayed, the appropriate proximity warning light representing the aircraft which caused the command is also illuminated and flashed.

METHOD OF APPROACH.

A preexperiment questionnaire was designed for purposes of determining optimum IPC display configuration(s). This questionnaire was presented to 17 professional personnel with an intimate knowledge of IPC (i.e., IPC program managers and pilots). This limitation was used to assure that the alternative display(s) chosen for simulation would have the functional priorities demanded by the IPC program. Fourteen displays were chosen and are verbally described in table 1 and pictorally represented in appendix A.

The 14 proposed display configurations were essentially characterized by a series of binary alternative choices in types of information which could be displayed:

1. The use of symbology versus word commands,
2. Altitude versus no altitude advisories (high, coaltitude, low),
3. The issuance of (do) positive versus (don't) negative commands, and
4. PWI Advisories versus no PWI advisories.

In addition to the above choices, all of the alternative displays that contained PWI advisory information eliminated the rear quadrants (i.e., clock positions 4 through 8) based on the fact that it has been demonstrated that this information is not usable by the pilot (reference 1).

Each IPC display configuration was defined by a series of binary choices as to the type of depicted IPC information. These choices or parameters are listed below and coded 0 or 1.

1.	Words (0)	vs.	Symbols (1)
2.	Positive Commands (0)	vs.	Negative Commands (1)
3.	PWI Ring (0)	vs.	No PWI Ring (1)
4.	Single Sector (0)	vs.	Split Sector (1)
5.	Sector Arrows (0)	vs.	Alt. Arrows - No sector lines (1)

The questionnaire score sheet is presented in table 2. The first column indicates the displays. The second column, Rank, is filled in by the subject. The third column, entitled Parameters, denotes the binary differences between the displays as described above. (For example, the parameters for the BADCOM

TABLE 1. PROPOSED ALTERNATIVE IPC DISPLAYS

NAFEC - 1	Negative words, IPC with PWI, Single Sector
NAFEC - 2	Negative words, IPC with PWI, Split Sector (±)
NAFEC - 3	Positive words, IPC with PWI, Single Sector
NAFEC - 4	Positive words, IPC with PWI, Split Sector (±)
NAFEC - 5	Negative words, IPC without PWI, No Sectors
NAFEC - 7	Negative words, IPC without PWI, No Sectors
TSC - 9	Negative Symbols, IPC with PWI, Altitude Arrows - No Sector Lines
TSC -10	Negative Symbols, IPC with PWI, Altitude Arrows - with Sector Lines
TSC -11	Negative Symbols, IPC with PWI, Split Sector (±)
TSC -12	Negative Symbols, IPC with PWI, Single Sector
TSC -13	Positive Symbols, with word commands, IPC with PWI, Altitude Arrows - No Sector Lines
TSC -14	Positive Symbols, with word commands, IPC with PWI, Altitude Arrows - with Sector Lines
TSC -15	Positive Symbols, with word commands, IPC with PWI, Split Sector (±)
TSC -16	Positive Symbols, with word commands, IPC with PWI, Single Sector.

display read, 1 1 0 - 1, which means that display utilizes (1) symbols, (2) negative commands, (3) a PWI ring, (4) no sectorization, and (5) altitude arrows without sector lines.)

From table 2, it is seen that there were 24 comparisons presented. The subjects were asked to rank each of the 24 three-display combinations separately. An artist's rendition, in color, of each of the three proposed display combinations was presented to the subjects to assist in his selection. The subjects were asked to rank the display combinations as follows: (1) best display, (2) next best display, and (3) least desirable display. These raw scores are summarized in table 3. The first column (P) is the frequency of appearance of the display in the questionnaire. The second column (E) is a sum of the raw scores. The third column presents the average score obtained by dividing the sum by the frequency. The last column is a ranking of the displays, indicating the best candidate (1) and the least probable candidate (15).

RESULTS.

A display feature-by-feature analysis of the results indicates that the subjects preferred positive commands, a split-sectored PWI ring, and symbology instead of words. None of the 14 proposed display combinations presented in the questionnaire met all of these requirements; therefore, a display designed to meet the above requirements was designed and fabricated in the form of a 3-inch-diameter simulated cockpit instrument as shown in figure 2. The BADCOM display was also fabricated in the form of a 5-inch-diameter simulated cockpit instrument.

PHASE II. OBJECTIVE SIMULATION EVALUATION

The second phase of this study involved the simulation of midair collisions in an IPC framework utilizing the optimum display from phase I and the BADCOM display. The Collision Prevention Laboratory at NAFEC was used as the simulation environment.

DESCRIPTION OF EQUIPMENT.

COLLISION PREVENTION LABORATORY. The Collision Prevention Laboratory consists of a GAT-2 flight simulator situated at the center of a spherical projection screen, 20 feet in diameter, an intruder aircraft projection system (figures 3 and 4), and a minicomputer.

The GAT-2 is a two-degree-of-freedom moving-base flight simulator and represents a light twin-engine propeller-driven aircraft. It is equipped with complete dual-instrumentation and navigation/communication capability.

The intruder aircraft projection system consists of a model Cessna 180 mounted in a specially designed two-axis (pitch, yaw) gimbal. A television camera is placed at a fixed focal distance from the Cessna 180 model to form

TABLE 2. IPC QUESTIONNAIRE SCORE SHEET

Display	Rank	Parameters					Display	Rank	Parameters				
		1	2	3	4	5			1	2	3	4	5
BADCOM		1	1	0	-	1	BADCOM		1	1	0	-	1
TSC-13		1	0	1	-	-	TSC-12		1	1	0	0	0
TSC-14		1	0	0	0	1	TSC-9		1	1	0	0	1
NAFEC-2		0	1	0	1	-	NAFEC-3		0	0	0	0	-
TSC-10		1	1	0	1	1	TSC-14		1	0	0	0	1
TSC-11		1	1	0	1	0	TSC-16		1	0	0	0	0
BADCOM		1	1	0	-	1	BADCOM		1	1	0	-	1
NAFEC-3		0	1	0	0	-	TSC-9		1	1	0	0	1
NAFEC-4		0	0	0	1	-	NAFEC-4		0	0	0	1	-
NAFEC-2		0	1	0	1	-	TSC-13		1	0	1	-	-
TSC-15		1	0	0	1	0	TSC-16		1	0	0	0	0
TSC-9		1	1	0	0	1	TSC-14		1	0	0	0	1
BADCOM		1	1	0	-	1	BADCOM		1	1	0	-	1
TSC-14		1	0	0	0	1	TSC-11		1	1	0	1	0
TSC-10		1	1	0	1	1	NAFEC-2		0	1	0	1	-
NAFEC-4		0	0	0	1	-	NAFEC-4		0	0	0	1	-
TSC-15		1	0	0	1	0	TSC-14		1	0	0	0	1
TSC-9		0	1	0	1	-	TSC-9		0	1	0	1	-
BADCOM		1	1	0	-	1	BADCOM		1	1	0	-	1
TSC-10		1	1	0	1	1	NAFEC-1		0	1	0	0	-
TSC-11		1	1	0	1	0	NAFEC-3		0	0	0	0	-
NAFEC-4		0	0	0	1	-	NAFEC-7		0	0	1	-	-
TSC-15		1	0	0	1	0	TSC-13		1	0	1	-	-
TSC-14		1	0	0	0	1	NAFEC-5		0	1	1	-	-
BADCOM		1	1	0	-	1	BADCOM		1	1	0	-	1
TSC-9		0	1	0	1	-	TSC-11		1	1	0	1	0
TSC-10		1	1	0	1	1	NAFEC-4		0	0	0	1	-
NAFEC-7		0	0	1	-	-	NAFEC-2		0	1	0	1	-
NAFEC-3		0	0	0	0	-	TSC-14		1	0	0	0	1
TSC-13		1	1	0	-	-	TSC-9		1	1	0	0	1
NAFEC-4		0	0	0	1	-	BADCOM		1	1	0	-	1
TSC-14		1	0	0	0	1	NAFEC-3		0	0	0	0	-
BADCOM		1	1	0	-	1	TSC-12		1	1	0	0	0
NAFEC-1		0	1	0	0	-	BADCOM		1	1	0	-	1
TSC-9		1	1	0	0	1	NAFEC-2		0	1	0	1	-
TSC-12		1	1	0	0	0	NAFEC-4		0	0	0	1	-

TABLE 3. QUESTIONNAIRE DATA SUMMARY TABLE

Display	P	E	Avg.	Rank
BADCOM	13	478	36.8	10
NAFEC 1	2	67	33.5	6
NAFEC 2	5	173	34.6	8
NAFEC 3	5	164	32.8	5
NAFEC 4	8	237	29.6	3
NAFEC 5	1	47	47	15
NAFEC 7	2	78	39	14
TSC 9	8	306	38.3	13
TSC 10	4	146	36.5	9
TSC 11	4	137	34.2	7
TSC 12	3	114	38	11.5
TSC 13	4	120	30	4
TSC 14	8	223	27.9	2
TSC 15	3	82	27.3	1
TSC 16	2	76	38	11.5
		2448		

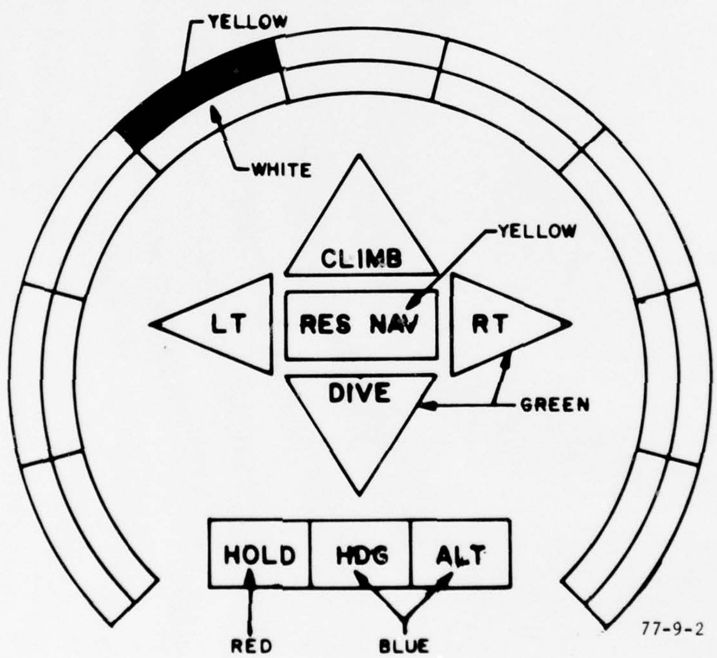


FIGURE 2. THE NAFEC-PROPOSED IPC DISPLAY

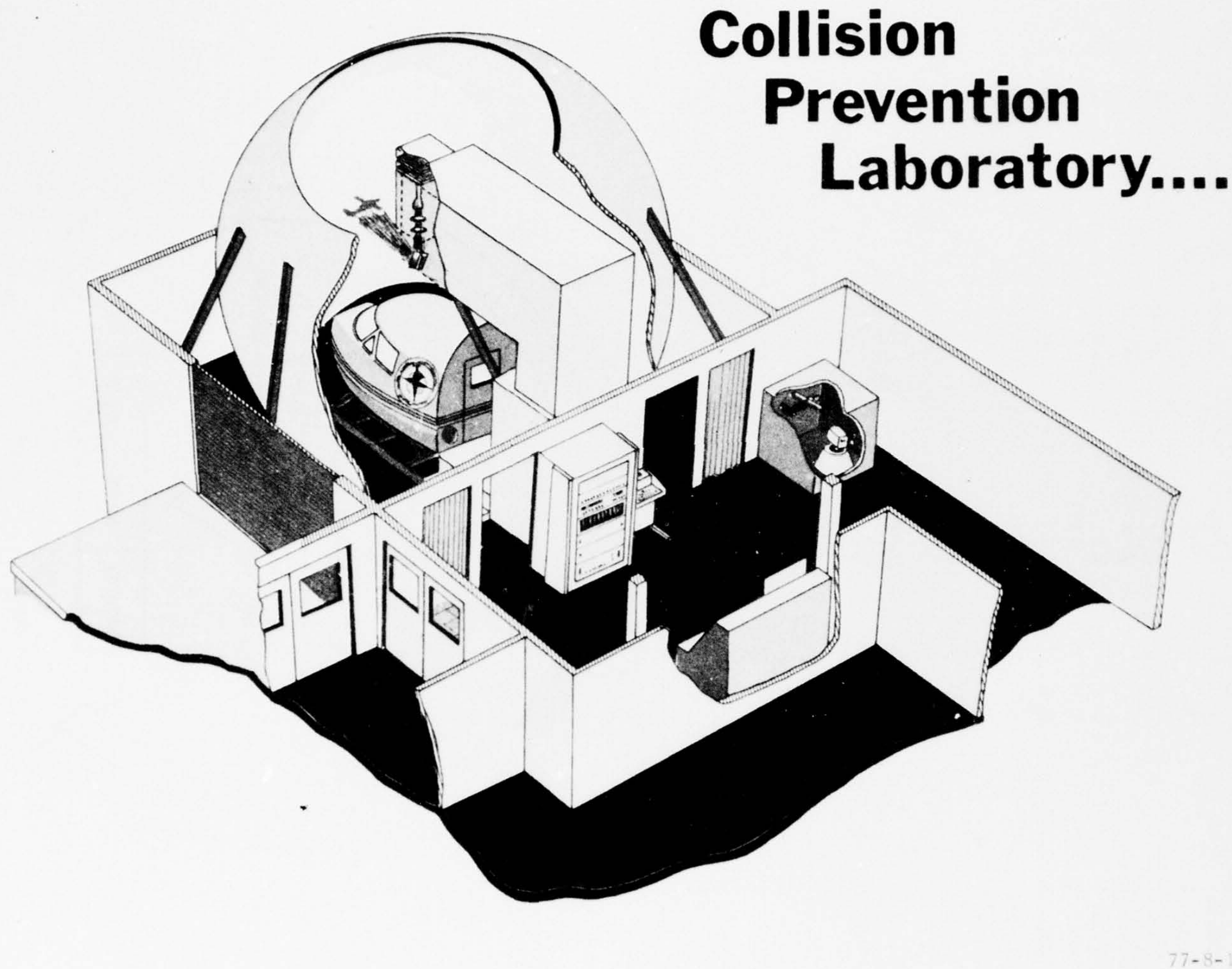


FIGURE 3. ARTIST'S RENDITION OF NAFEC COLLISION AVOIDANCE LABORATORY

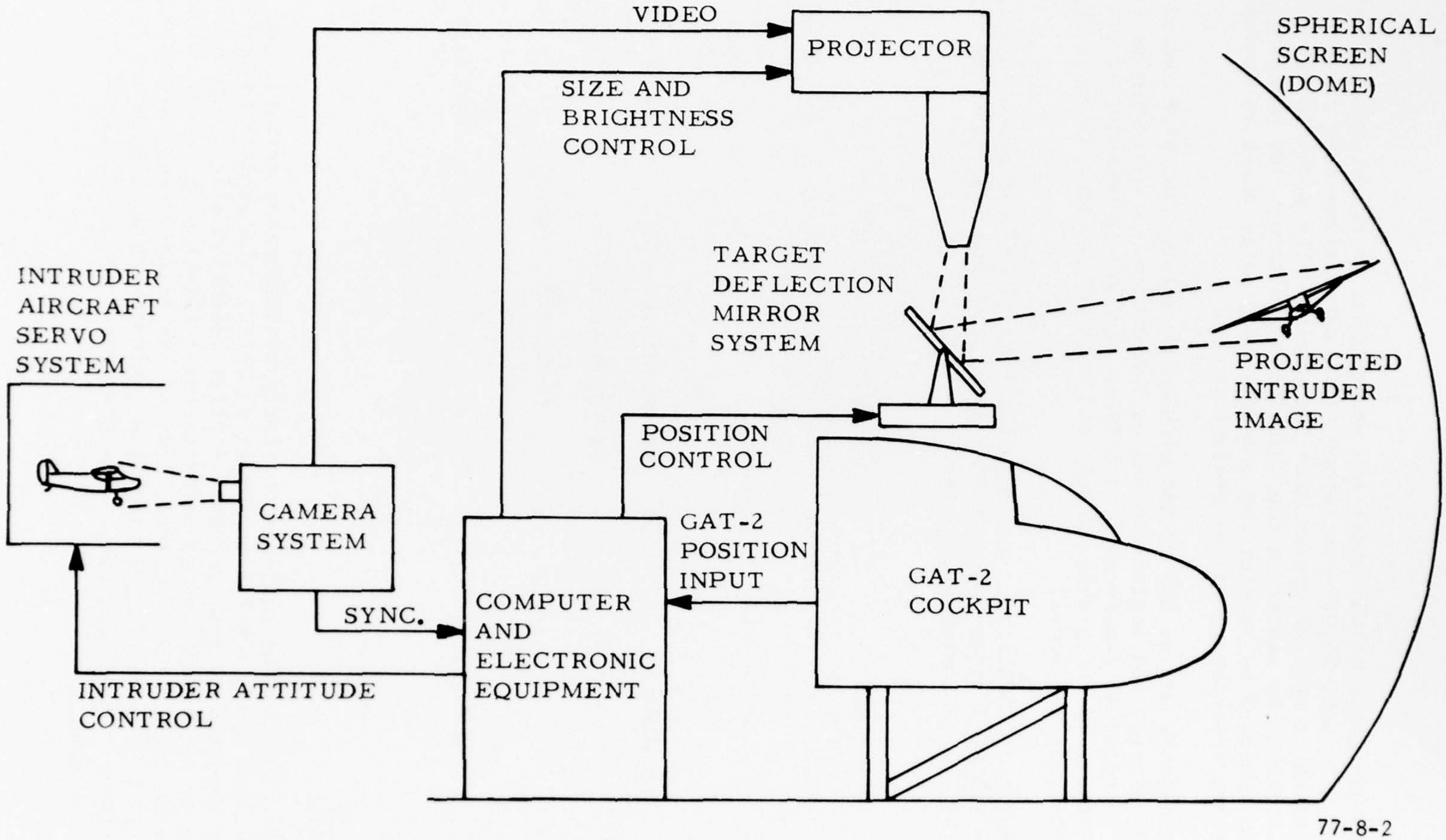


FIGURE 4. SCHEMATIC DIAGRAM OF INTRUDER AIRCRAFT PROJECTION SYSTEM

an electronic image of the model for projection. A television projector employing a 5-inch, 15,000-footlambert (fL) cathode-ray tube projects the image through an optical system onto the sphere. The model is simulated to bank by rolling the raster in the television projector, and the range/closure effect is achieved by varying the intruder image size which is accomplished by shrinking the rasters in the projector.

The minicomputer was an XDS CF-16A with an 8K memory core with associated analog-to-digital and digital-to-analog converters. A minicomputer controls all the coordinate transformations between the GAT-2, intruder aircraft model gimbal system, mirror gimbal system, and horizon gimbal system, as well as the aerodynamics of the model.

EXPERIMENTAL IPC DISPLAYS. The displays chosen for evaluation in this phase were the BADCOM display and a "NAFEC" display. These displays are characterized by the following attributes:

	Attribute	"BADCOM"	"NAFEC"
1.	Commands	A. Negative/Positive B. Crosses/Arrows	A. Positive B. Diamond-shaped arrows C. Positive words D. "Do"
2.	Altitude	A. Arrows/Circles (3) 1. High (Blue) 2. Coaltitude (Amber) 3. Low (Green)	A. Sector Segments (2) 1. High (Yellow) 2. Low (White)
3.	PWI Advisory	A. Unsectored B. Altitude Advisory Light, 30° Spacing	A. Sectored B. 30° Spacing

DISCUSSION.

SUBJECTS. Twenty-four subjects currently holding pilot certificates were selected from among the FAA employees at NAFEC. The subject pilots were randomly assigned to four groups. A pilot selection effort was made to use pilots with relatively low to moderate total flight hours, i.e., less than 1,000 hours total time. However, four of the selected subject pilots had relatively high total flight time (i.e., greater than 2,000 hours total flight time). These four subject pilots were randomly assigned, one each to the four groups.

SESSIONS. Each subject was asked to complete four 40-minute sessions. During each of these sessions, the subject pilot was subjected to 15 simulated intruder targets. The 15 targets consisted of the combinations resulting from the five azimuth sectors by three initial altitudes (high, coaltitude, low) variables. Each group of subject pilots used both IPC displays in the following four display/procedure combinations:

t_1. BADCOM with maneuver commands

t_2. BADCOM without maneuver commands--warning advisory only

t_3. NAFEC with maneuver commands

t_4. NAFEC without maneuver commands--warning advisory only

It was not possible to randomize the order of presentation of the display/procedure combinations for each trial due to the complexity of the hardware installation in the instrument panel of the GAT-2 cockpit. However, the presentation of the four display/procedure combinations was counterbalanced such that no two groups of subject pilots followed the same order of presentation. The order of presentation is shown in table 4.

TABLE 4. EXPERIMENTAL DESIGN AND ORDER OF PRESENTATION OF DISPLAY CONDITIONS

SESSION

	1	2	3	4
Group 1	t_1	t_2	t_3	t_4
Group 2	t_2	t_1	t_4	t_3
Group 3	t_3	t_4	t_1	t_2
Group 4	t_4	t_3	t_2	t_1

t_1 = BADCOM with maneuver commands

t_2 = BADCOM without maneuver commands

t_3 = NAFEC with maneuver commands

t_4 = NAFEC without maneuver commands

TARGET AIRCRAFT PRESENTATION. The initial start range for all simulated intruder targets was 2.0 nautical miles (nmi) from the GAT-2's origin. The simulated intruder targets were randomized to start above, at the same altitude, and below the GAT-2 altitude. Initial start-point angles were further randomized between 10, 11, 12, 1 and 2 o'clock azimuth positions. Each target presentation was preceded by an aural alert tone presented to the subject pilot in the GAT-2 cockpit to assure pilot awareness of the target. All targets were programmed on a rectilinear collision course with the GAT-2's origin.

SUBJECT PROCEDURE. The subject pilots were briefed on the purpose of the study and throughly acquainted with the two experimental IPC displays. Each of the two experimental IPC displays were presented to the subject pilots under two different operational procedures. The first procedure (display + warning + command) presented the PWI (warning) portion of the display first (initial intruder altitude and azimuth). The subject pilot was instructed to acquire the simulated intruder target visually and then follow its flightpath while continuing his current navigation tasks in the GAT-2. When the simulated intruder target had reached a point 0.75 nmi from the current GAT-2 origin, an IPC avoidance maneuver command was displayed (in a flashing mode). The subject pilot was instructed to await this command and then immediately execute the maneuver command (by making the required evasive maneuver). The second procedure (display + warning only) presented the PWI warning portion of the display (initial intruder altitude and azimuth). The subject pilot was instructed to acquire the simulated intruder target visually and then, at his discretion, execute whatever evasive maneuver he felt would have been necessary to avoid the simulated intruder target. At the completion of the evasive maneuver(s), the subject pilot was instructed to return to his initially assigned heading and altitude and to continue his assigned navigational duties while awaiting the presentation of the next simulated intruder target.

EXPERIMENTAL DESIGN. The experimental design used in this experiment was a split-plot factorial design, with one between and three within-subject variables (reference 2) (SPF 2.253 design, Kirk, 1969, pages 208-311). The between-subject variable was the order of presentation of the four display procedure combinations. The within-subject variables were the four display/procedure combinations (t_1, t_2, t_3, t_4), the five azimuth sector positions (10, 11, 12, 1, and 2 o'clock), and the three initial altitudes, , high (+500 to +2,000 feet), coaltitude (+500 to -500 feet), and low (-500 to -2,000 feet).

DATA COLLECTION. An eight-channel EAI strip-chart recorder was used to record the following parameters from the GAT-2 analog and digital sources:

1. Elapsed time from presentation of the simulated intruder target to point of initial evasive maneuver;

2. Distance of the simulated intruder target from the GAT-2's origin at the point of initial evasive maneuver;

3. Directional and positional information (heading, pitch, and roll) from the GAT-2 prior to and during the evasive maneuver; and

4. Airspeed (GAT-2).

TABLE 5. ANALYSIS OF VARIANCE SUMMARY TABLE

This table presents the analysis of variance summary for evaluating the effect of groups (order of presentation), display-procedures, sectors, and initial altitude of the simulator intruder aircraft on the initial maneuver distance that existed at the time the subject pilot began his initial maneuver to avoid the simulated intruder aircraft.

Source	Sum of Squares	df	Mean Square	F Ratio	Probability
Groups (Order) (A)	6.742	3	2.247	1.559	.230
Between Error	28.830	20	1.442		
Display-Procedure (B)	11.792	3	3.931	5.984	.002
AxB	8.311	9	.923	1.406	.206
Within Error - 1	39.408	60	.657		
Sectors (C)	1.234	4	.308	6.204	.001
AxC	1.381	12	.115	2.315	.014
Within Error - 2	3.977	80	.050		
Initial Altitude (D)	1.602	2	.801		
AxD	.428	6	.071	7.339	.002
Within Error - 3	4.367	40	.109		
BxC	1.457	12	.121	2.687	.002
AxBxC	3.265	36	.091	2.007	.001
Within Error - 4	10.847	240	.045		
BxD	1.813	6	.302		
AxBxD	.827	18	.046	4.309	.001
Within Error - 5	8.413	120	.070		
CxD	.725	8	.091	1.653	.113
AxCxD	1.400	24	.058	1.063	.391
Within Error - 6	8.777	160	.055		
BxCxD	1.176	24	.049	1.136	.298
AxBxCxD	3.952	72	.055	1.273	.076
Within Error - 7	20.697	480	.043		
Total	171.421	1437	.119		

RESULTS.

An analysis of variance (ANOVA) was completed on the actual measured distance between the simulated intruder target and the GAT-2 that existed at the time the subject pilot began his initial maneuver to avoid the simulated intruder target. The ANOVA summary table is presented in table 5. The results of the ANOVA on the initial maneuver distance revealed that the groups (i.e., order of presentation of the display-procedure combinations) failed to attain statistical significance ($F = 1.559$, $df = 3, 20$, $P < .23$). Hence, the null hypothesis (no marked differences attributable to order of presentation) was not rejected. The means for the order of presentation (groups 1-4 by display-procedure combinations) are presented in table 6. The number in the upper left corner corresponds to the actual order in which the four display-procedure combinations were presented to the subjects within a group. It would appear, from the data in table 6, that there may have been a small practice effect due to order of presentation of the display-procedure combinations (i.e., the last (4th) presented display-procedure combination resulted in the shortest overall initial maneuver distance. However, since the presentation of the display-procedure combinations was counterbalanced, the effect on the data is not significant.

TABLE 6. MEAN INITIAL MANEUVER DISTANCES FOR ORDER OF PRESENTATION BY DISPLAY PROCEDURE INTERACTION

	t_1	t_2	t_3	t_4	
Group 1	1st 0.717	2nd 0.847	3rd 0.690	4th 0.661	.729
Group 2	2nd .736	1st 1.000	4th .711	3rd 1.042	.872
Group 3	3rd .682	4th .717	1st .710	2nd .753	.718
Group 4	4th .689	3rd 1.067	2nd .678	1st .946	.845
	.708	.908	.697	.850	

The results of the ANOVA for the groups by display-procedure interaction indicated that there was no significant effect ($F=1.406$, $df=9, 60$, $P < .206$). The results of the ANOVA for the main effect of display-procedure combination was significant ($F=4.984$, $df=3,60$, $P < .002$). The means for the four display-procedure combinations are presented in table 7.

TABLE 7. MEAN INITIAL MANEUVER DISTANCES AND ELAPSED TIMES FOR THE FOUR DISPLAY-PROCEDURE COMBINATIONS

Warning/Command	Warning-Only
BADCOM (${}^{t}1$) 0.708* nmi 21.989** seconds	BADCOM (${}^{t}2$) 0.908 nmi 18.475 seconds
NAFEC (${}^{t}3$) .697 nmi 22.042 seconds	NAFEC (${}^{t}4$) .850 nmi 18.428 seconds

* Distance in nautical miles
** Elapsed time (seconds) from appearance of simulated intruding target to start of initial avoidance maneuver.

It will be noticed from table 7, that there exists a distinct difference between using the displays in a warning/command mode and using the displays in a warning-only mode. In the warning/command mode, the subject pilots appeared to have waited for the maneuver commands as directed and to have responded to the maneuver commands almost immediately for both the NAFEC and the BADCOM displays; whereas, the subject pilots in the warning-only mode responded with a maneuver at the distance which they perceived the simulated intruder target to be a real threat. It may therefore be concluded that the subject pilots would respond to a warning of a potential threat at an initial distance greater than that at which the final maneuver command would be issued (i.e., a distance greater than 0.750 nmi). From the results in table 7, it appears that in the warning-only case, there might be a difference between the subject pilot reaction to the unsectorized BADCOM display and the sectorized NAFEC display; however, when a Scheffe' ratio was calculated for the observed means, the result was not significant (Scheffe' ratio: 6.138 <12.39--see appendix B).

The results of the ANOVA for the main effect of sectors was significant ($F = 6.204$, $df = 4, 80$, $P<.001$), as was the main effect for initial intruder altitude of the simulated intruder target ($F = 7.339$, $df = 2, 40$, $P <.002$). However, the sectors by initial altitude interaction was not significant ($F = 1.653$, $df = 8, 160$, $P <.113$). The means for the sectors by initial intruder altitude interaction are presented in table 8. From table 8, the significant difference due to sector and intruder altitude can be seen. The sector differences favor the straight-ahead segments in that they are responded to at a greater distance. The intruder altitude differences can also be seen from this table. From table 8, it can be seen that the low and coaltitude are responded to differently than the high-altitude targets. Both of these effects are examined in detail in figures 5 and 6.

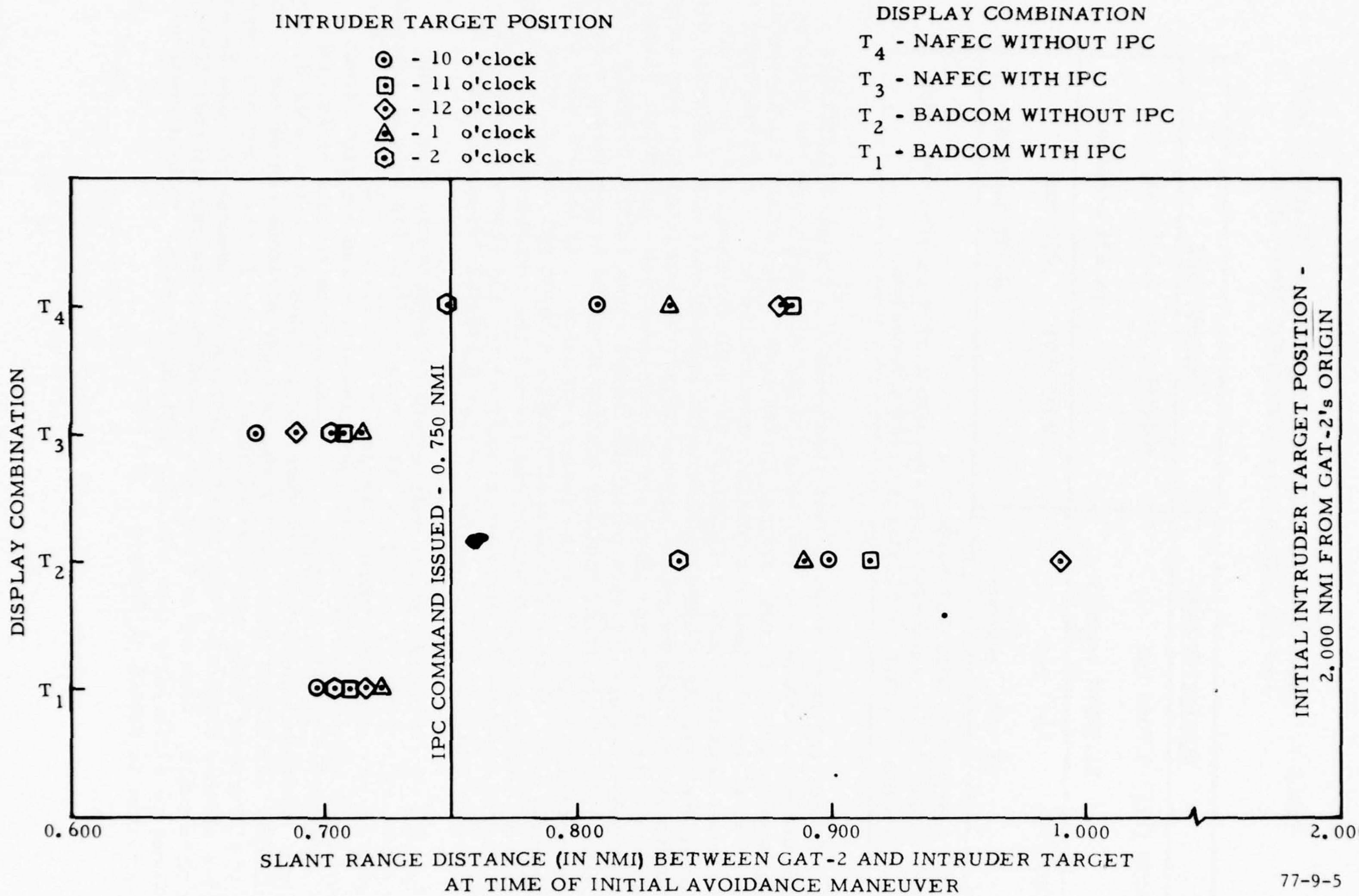


FIGURE 5. DISPLAY-BY-SECTOR INTERACTION

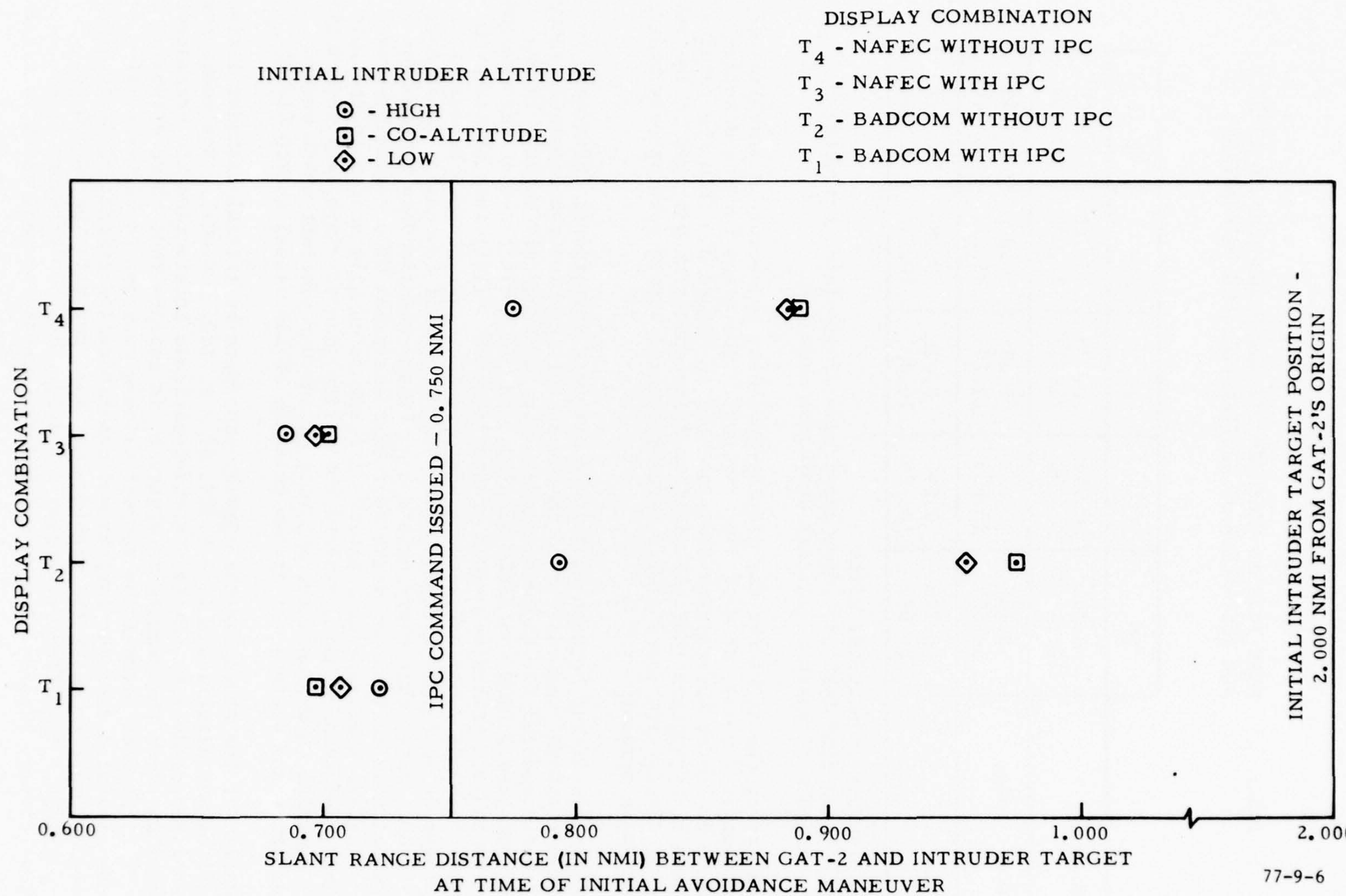


FIGURE 6. DISPLAY-BY-ALTITUDE INTERACTION

TABLE 8. MEAN INITIAL MANEUVER DISTANCES AND ELAPSED TIMES FOR THE SECTOR BY INITIAL ALTITUDE INTERACTION

	10	11	12	1	2
High	0.741 22.458**	0.776 21.750	0.779 18.573	0.768 21.937	0.655 23.458
Coaltitude	0.755 18.615	0.828 20.875	0.885 17.073	0.810 21.021	0.783 18.448
Low	0.796 21.073	0.840 20.729	0.828 16.896	0.789 20.594	0.811 20.000

* Distance in nautical miles

** Elapsed time (seconds) from appearance of simulated intruding aircraft to start of initial avoidance maneuver.

The results of the ANOVA for the display-procedure by sector interaction was significant (F = 2.687, df = 12,240, P <.002). The means for the display-procedure by sector interaction are presented in figure 5. From the results in figure 5, it appears that the distinct difference that was seen in the main effect of display-procedure (i.e., warning/command versus warning-only modes) becomes quite evident.

From figure 5, it can be seen that there exists a significant difference in the subject pilots' response based on the sector in which the simulated intruder target was presented for the warning-only display-procedure modes. In the case of both the BADCOM and NAFEC displays, the 12 o'clock sector was responded to by the subject pilots at a much greater distance (i.e., initial maneuver distance) than the 2 o'clock sector; whereas, the other sectors tended to cling together in terms of the subject pilots' initial response. These data would tend to infer that there exists a nonlinear relationship between the sectors which is influenced by the fact that the pilot of a representative small or medium-size general aviation aircraft is usually seated in the left hand seat, and as such has a reduced capability, due to visibility restrictions of the cockpit, to evaluate the activity of another aircraft which occurs in the right-hand sectors (or at the extremes of his visual search field).

The results of the ANOVA for the display-procedure by initial intruder altitude interaction was significant (F = 4.309, df = 6, 120, P <.001). The means for the display-procedure by initial-intruder-altitude interaction are presented in figure 6. From the results in figure 6, it appears that there exists a distinct difference between the subject pilot's response to high-initial-altitude simulated intruder targets and coaltitude/low-initial-altitude simulated intruder targets under the warning-only mode for both the BADCOM and NAFEC displays. This finding, argues strongly for a two-category (i.e., high/low) display presentation as opposed to a three-altitude category display

presentation, since the subject pilots were not able to discriminate significantly between coaltitude and low-altitude targets based on the information contained in the BADCOM warning-only display presentation.

ANALYSIS OF IPC PILOT QUESTIONNAIRE.

A pilot questionnaire (appendix C) was presented to each pilot upon completion of his flight requirements for evaluation of the BADCOM and NAFEC IPC displays. A series of questions on each display was asked, as well as questions applicable to both displays. A selected few questions have been designated as key questions which answered the major aspects of the displays and their associated algorithms. Pilot response to the individual displays was as follows:

BADCOM. As shown (figure 1) the warning portion of the display consisted of three symbols to designate target altitude. A blue triangle (∇) depicted targets above; an amber round circle (O) depicted targets at the same altitude, and an inverted green triangle (∇) for targets below. These three symbols were located vertically stacked in each of the clock positions and, when lit, designated the targets relative azimuth position. For this experiment, only the 10, 11, 12, 1, and 2 o'clock positions were used.

1. A high percentage of the pilots were unable to determine target elevation by color alone (63) or by the shape of the triangles (58), and attributed this to the small physical size of the triangles and the difficulty in distinguishing the blue and green colors.

2. Target azimuth was not easily recognized, due to the subdued ambient lighting in the cockpit and no integral lighting of the display face itself.

The IPC maneuver command portion of the display consisted of four green arrows with a red "X" superimposed on both of the turn arrows and a solitary red "X" for the climb and dive arrows. When lit, these red "X's" inferred a "don't" command for that particular directional maneuver.

1. The pilots experienced little difficulty in discerning or interpreting the green arrows.

2. All of the pilots showed preference for green arrows rather than another color.

3. The pilots were closely divided in their opinion of the red "X" causing any confusion;

a. Yes 13%
b. Sometimes 41%
c. No confusion 46%

4. A majority of the pilots felt that the individual climb and dive arrows should also have a red "X" on them and that given negative commands, a red "X" was a satisfactory method of displaying them.

5. The necessity of distinguishing positive commands from negative commands resulted in:

a.	No trouble	54%
b.	Occasional	46%
c.	Considerable	-

6. Pilot preferences for displaying the BADCOM maneuver commands were:

a.	All positive and negative commands ON steadily	46%
b.	Negative commands flashing; positive commands steady	8%
c.	Positive commands flashing; negative commands steady	46%
d.	All positive and negative commands flashing	-

NAFEC. The warning portion of the NAFEC display (figure 2) consisted of nine 30° ring segments covering 270° in azimuth around the pilot. Each segment was divided into two equal parts; an upper (or outer) part colored yellow and signifying that targets were located from the horizon and upward, a lower (or inner) part colored white for targets from the horizon and below.

1. Most of the pilots determined target elevation by segment position (outer versus inner) as opposed to segment color.

2. Pilot difficulty in determining whether the target was above or below was:

a.	Considerable	4%
b.	Occasional	54%
c.	None	42%

The IPC maneuver command portion of this display consisted of four large, green triangles, one on each major compass point (N, S, E, W), with an appropriate command written (or abbreviated) in each triangle. In addition, a "hold/heading/altitude" command bar simultaneously displayed instructions.

1. The majority of pilots used the triangular shape of the command triangles (as opposed to lettering) to determine the appropriate maneuver direction.

2. The "hold heading/altitude" command bar was easily interpreted and caused no significant confusion.

3. Pilot preference for displaying the NAFEC maneuver commands were:

a.	All commands on steady	58%*
b.	Triangles flashing; hold commands steady	33%
c.	Triangles steady; hold commands flashing	9%
d.	All commands flashing	-

*Note: All IPC commands were given in the "steady" state for this experiment.

4. When the resume navigation bar was lit, it signified that the threat had passed and was of significant importance to the pilots.

5. Overall operational brightness of the displays was rated:

		BADCOM	NAFEC
a.	Very poor	34%	-
b.	Acceptable	54%	70%
c.	Very good	12%	30%

6. The issuance of the IPC evasive maneuver command was made 3/4 nmi from intruder and was considered sufficient for evasive action by the pilots.

To answer certain key questions, pilot preferences were as follows:

1. Pilot preference for the four display conditions were:

a.	NAFEC with IPC commands	1st
b.	BADCOM with IPC commands	2nd
c.	NAFEC without IPC commands	3rd
d.	BADCOM without IPC commands	4th

2. The majority of the pilots preferred positive commands; that is, "tell me to DO something", or "what I CAN do"; not "what I CAN'T do".

3. Pilots indicated a preference for a three-position reference PWI for displaying target altitude (above - same altitude - below). However, the objective data indicate they cannot discriminate between coaltitude/low designators.

4. All things considered, 88 percent of the pilots felt that the NAFEC display would be best suited for potential use in the ATC system.

There were obvious desirable features of both displays, and it was thought that perhaps the pilots might have some difficulty with interpretation and execution of certain symbologies of a particular display. However, no significant difficulty was evident. There were numerous occasions when the pilots were in disagreement with the evasive maneuver as issued by the displays,

and this was evidenced by the pilots overwhelming use of multidirectional maneuvering; i.e., dive and turn, climb and turn. The use of a multidirectional evasive command was not a part of the algorithm of either display. Only unidirectional maneuvers were depicted.

SUMMARY OF RESULTS

Based on a subjective comparison of 14 proposed alternative IPC display designs and an objective simulator test comparing the utility of a new display which incorporated the desirable features derived from the 14 alternative displays, versus the utility of the original IPC BADCOM display, it was found that:

1. Both displays were satisfactory for displaying IPC commands and PWI advisories; however, the pilots indicated that they preferred the NAFEC display, in that it commanded them to DO something.

2. In the proximity-warning-only mode, straight-ahead targets (11, 12 o'clock) resulted in quicker initiative of avoidance actions than did targets in other sectors. This result was attributed to the pilots seating position and the existing cockpit visibility restrictions.

3. In the proximity-warning-only mode, the pilots were not able to discriminate significantly between coaltitude and low-altitude targets but did make a distinction between high-altitude targets and coaltitude/low-altitude targets.

4. Collision avoidance performance in terms of timeliness is more consistent when specific maneuver commands are displayed in that the pilots immediately perform the required maneuver under all conditions. In this study, the pilots indicated that the 3/4-mile distance was sufficient for evasive action.

CONCLUSIONS

It is concluded that:

1. There was no overall significant difference between the measured pilot performance using the two displays evaluated.

2. The two-sector altitude presentation (NAFEC display) was significantly better than the three-sector presentation (BADCOM display).

3. The rear sector should not be displaced to the pilot (determined from previous effort reference 1).

4. The resume navigation command was found to be significantly important to the pilots from the subjective evaluation.

5. The pilots preferred the NAFEC display because of the positive command approach.

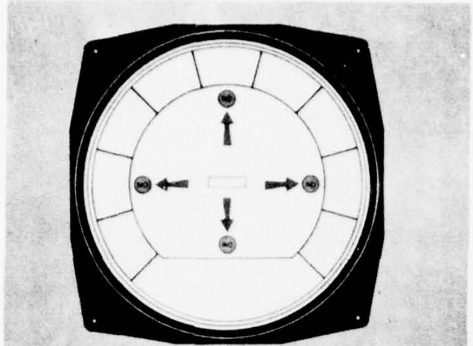
REFERENCES

1. Rich, Paul M., et al., Reactions of Pilots to Warning Systems for Visual Collision Avoidance, FAA-RD-71-61, December 1971.

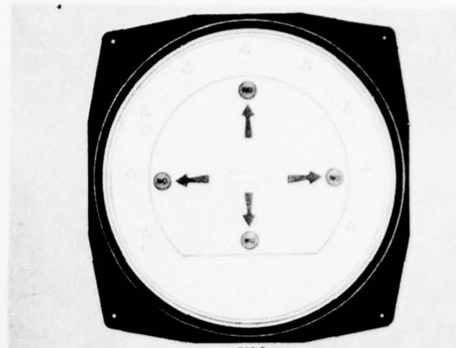
2. Kirk, R. E., Experimental Design: Procedures for the Behavioral Science, Belmont, California, Brooks/Cole Publishing Company, 1968.

APPENDIX A

FOURTEEN ALTERNATIVE IPC DISPLAY CONFIGURATIONS



TSC-12



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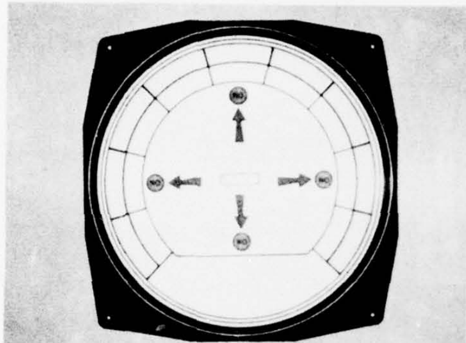
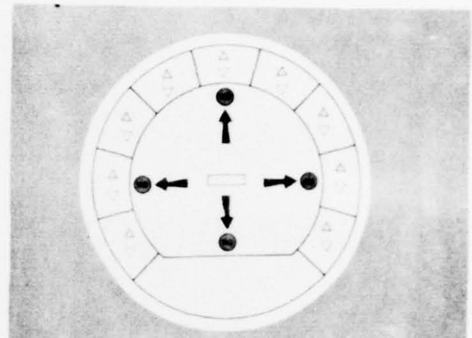
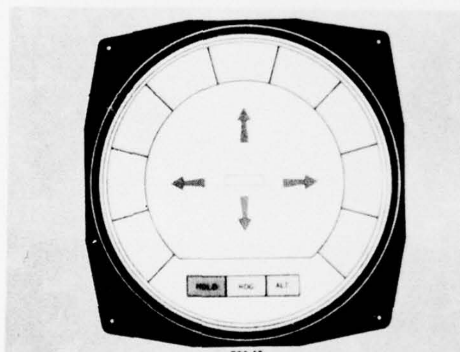


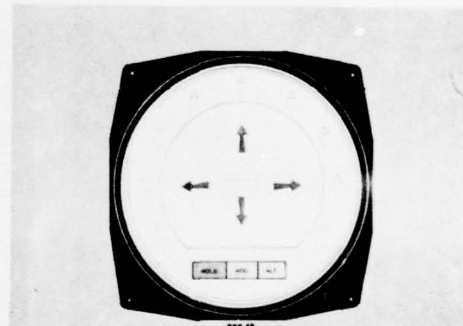
TSC-11



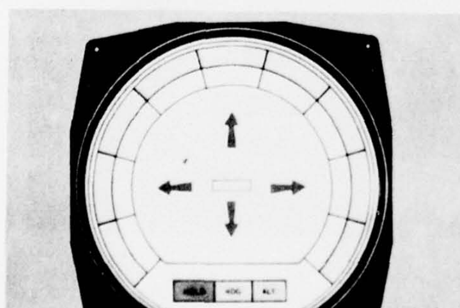
TSC-10



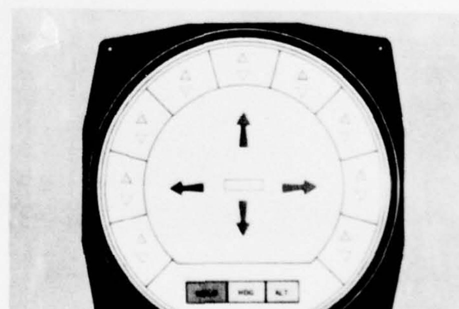
TSC-16



TSC-13

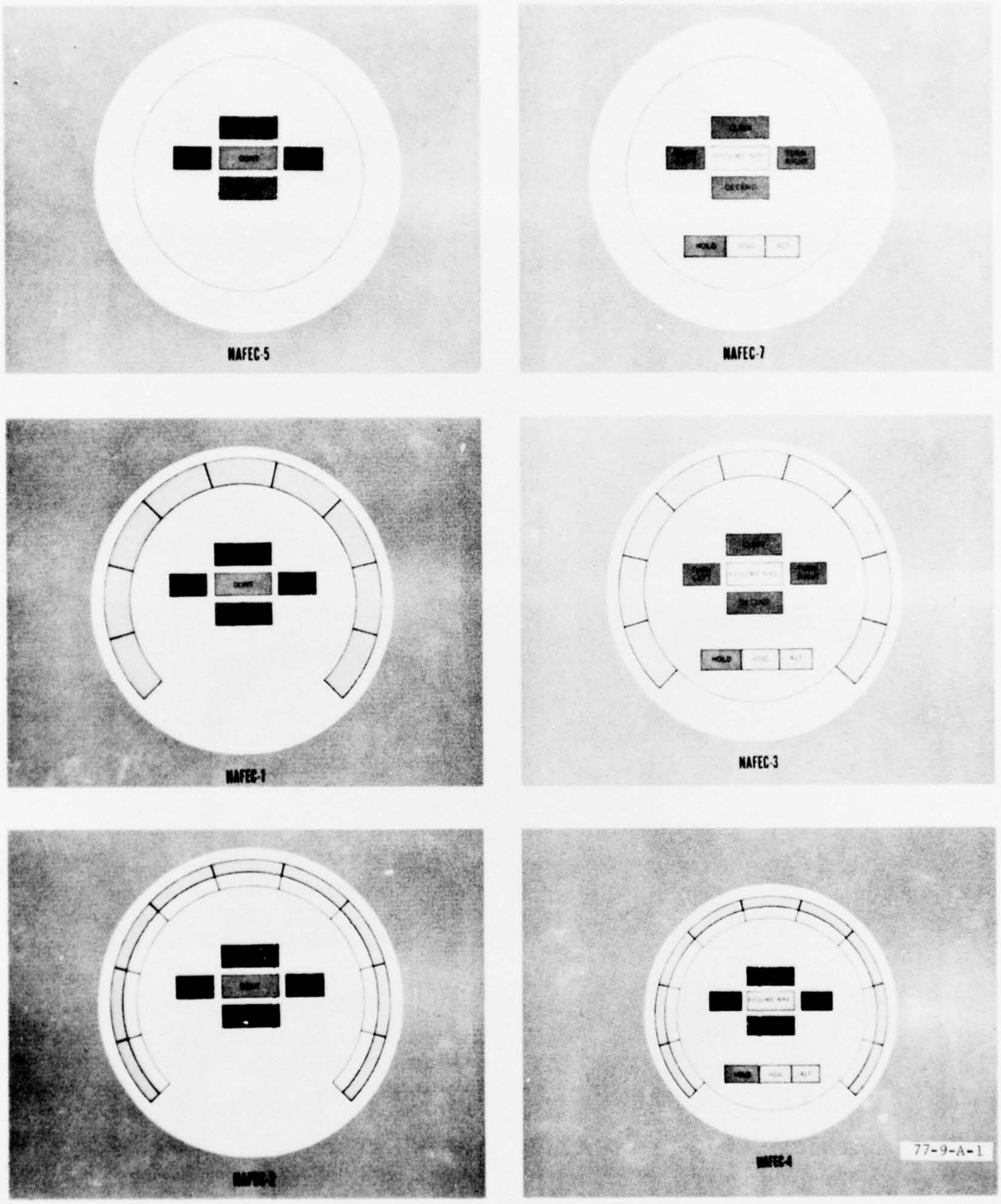


TSC-15



TSC-14

77-9-A-1


NAFEC-5
NAFEC-7
NAFEC-1
NAFEC-3
NAFEC-4
77-9-A-1

APPENDIX B

SCHEFFE's RATIO

Experiments of the type conducted in this study are designed to determine if any treatment effects are present. If an overall test of significance leads to a rejection of the null hypothesis, attention is directed to exploring the data in order to find the source of the effects. A number of "after the fact" test statistics have been developed for the function and among them is Scheffe's Ratio. This statistic can be used to make all possible comparisons among the treatment means and is based on the Mean Square Error obtained from the analysis of variance summary table. The formula for Scheffe's ratio is:

$$F = \frac{\left(C_j(x_j) + C_{j'}(x_{j'})\right)^2}{MS_{error}\left(\frac{(C_j)^2}{N_j} + \frac{(C_{j'})^2}{N_{j'}}\right)}$$

where C_j = coefficient of the contrast

In order to be significant, F must exceed $\hat{F}$, where $\hat{F} = (k-1)F_{\alpha, v_1, v_2}$. This value is obtainable from the standard F tables.

Reference: Kirk R.E. (Op.Cit.) page 90-91. (1968).

BADCOM without IPC commands vs. NAFEC without IPC commands, t_2 vs. t_4

$$F = \frac{1\ (.908) - 1\ (.850)^2}{.657\ \left(\frac{(1)^2}{24} + \frac{(-1)^2}{24}\right)}$$

$$F = \frac{.3364}{.657\ (.0833)}$$

$$F = \frac{.3364}{.0548}$$

$$F = 6.138$$

$$(K-1)\ F_{.01;3,60} = (4-1)\ (4.13)$$

$$= 3\ (4.13)$$

$$= 12.39$$

$6.138 < 12.39$ Therefore, Display t_2 does not significantly differ from Display t_4.

APPENDIX C

PILOT QUESTIONNAIRE

With reference to figure 1, the BADCOM Display, please answer the following:

1. Were you able to determine target elevation (above, same altitude, below) by color alone?

   Yes No

   Comment:______________________________

2. Were you able to determine target elevation by shape alone?

   Yes No

   Comment:______________________________

3. Was the triangular direction (Δvs. ∇) of the upper and lower elevation lights clearly discernable?

   Yes No

   If no, was this primarily due to:

   Size __ Lighting __
   Position of Display on the instrument panel __

4. Was azimuth recognition clear? If not, please explain why?

   Yes __ No __

   Comment:______________________________

   ____

   With regard to the IPC portion of the display:

5. Were the green command arrows clearly discernable?

   Yes __ No __

6. Did you experience any difficulty in correctly interpreting any of the command arrows?

   Yes __ No __

   Comments: ______________________________

7. Would you prefer a different color for the command arrows?

Yes __ No __
If yes, what color? ______________

8. Did the red X's (signifying a negative command) cause any confusion?

Sometimes __ Yes __ No __

If so, in what way: ____

9. Should the climb and dive arrows include a red X on them also?

Yes ___ No ____

10. Given negative commands, do you feel red X's are the best means of displaying them?

Yes __ No __

11. Is the use of "negative commands" an acceptable philosophy for pilot action in a collision avoidance situation?

Acceptable __ Not Desirable __ Totally Unacceptable __

12. Were you able to quickly distinguish the positive command from the negative command and react properly?

No trouble __ Occasional Confusion ___ Considerable Trouble __

13. State your preference with respect to displaying the BADCOM IPC commands.

a. All positive and negative commands on steady _______
b. Negative commands flashing; positive commands steady _______
c. Positive commands flashing; negative commands steady _______
d. All positive and negative commands flashing _______

With reference to figure 2, the NAFEC display, please answer the following:

1. Did you have any difficulty determing target elevation (above - same altitude - below)?

2. In determining target elevation, what display factors did you use?

a. Position only (outer ring segments vs. inner ring segments) __
b. Mostly position __
c. Both position and color equally __
d. Mostly color __

3. Was the direction of the four command triangles clearly discernable?

Yes __ No __

4. Did you have any difficulty identifying the climb/dive, left/right commands?

Yes __ No __

5. In determining left/right or climb/dive commands, what display factors did you use?

a. triangles only __
b. mostly triangles __
c. triangles and lettering equally __
d. Mostly lettering __
e. Lettering only __

6. When the left/right and climb/dive commands and the hold heading/altitude commands were lit simultaneously, did the total command cause any confusion?

Yes __ No __

If yes, comment: ____

____

7. Considering the hold heading/altitude command bar alone, did you have any difficulty determining one from the other?

Considerable Difficulty _____ Some _____ None _____

8. Not considering colors; which of the following factors did you use in determining the hold heading/altitude commands?

a. Position only (next to each other vs. separated) __
b. Mostly position __
c. Position and lettering __
d. Mostly lettering __
e. Lettering only __

9. State your preference with respect to the display of the NAFEC IPC commands.

a. All steady __
b. Triangles flashing; hold commands steady __
c. Triangles steady; hold commands flashing __
d. All flashing __

10. When "RES NAV" (resume navigation) was lit, it signified the threat had passed. Is this information of significant importance?

Definitely __ Of marginal value __ Could do without __

11. From a pilot's standpoint, which of the two displays do you feel must be considered for potential use in an ATC System?

BADCOM __ NAFEC __

12. Please rate the overall operational brightness of the displays.

	BADCOM	NAFEC
Very poor	__	__
Acceptable	__	__
Very good	__	__

13. Rank the following display conditions you flew (1-2-3-4).

a. BADCOM with IPC commands __
b. BADCOM without IPC (PWI only) __
c. NAFEC with IPC commands __
d. NAFEC without IPC (PWI only) __

14. Did you prefer: Check One

a, Negative commands (i.e., Arrows with X's) a. ____
b. Positive commands (i.e., Hold-HDG-ALT) b. ____

Comment: ____

____

15. Did you prefer: Check One

a. Coaltitude, Above, Below Indicator Lights a. ____
b. Yellow/White (Above/Below) Sectors b. ____

Comment: ____

____

16. Do you think that the timing of the IPC commands gave you enough time to maneuver?

Just Right ___ Too Early __ Too Late ___

Comment: ____

____

Please answer the following question regarding the IPC displays you have just flown for us. Thank you.

When directed by the IPC command to execute a specific avoidance maneuver, how often did you really agree with the maneuver?

Always __ Most of the time __ Only occasionally __ Rarely __

Comment: ____

____